PUPILLARY SIZE CHANGES DURING INFORMATION PROCESSING OVERLOAD

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THESIS

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INFORMATION PROCESSING OVERLOAD

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Information Processing Overload

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ABSTRACT

Pupillary size changes were investigated during a one-bit and two-bit information processing task. For an information processing task, a random list of the digits two and three and a random list of the digits one, two, three, and four were presented visually on a digital readout by means of a paper tape reader for a one-bit and two-bit task, respectively. The subject's required response was to depress a pushbutton switch corresponding to the digit presented on the digital readout. For both the one-bit and two-bit tasks, pupil diameter increased with an increasing information processing rate, reached a maximum at maximum information processing capacity, and rapidly constricted as maximum information processing capacity was exceeded.

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I. INTRODUCTION

The autonomic nervous system is composed of the parasympathetic division and the sympathetic division. The changes in pupil diameter due to changing light intensity have long been acknowledged and are controlled by the parasympathetic division. The changes in pupil diameter due to mental activity and emotional state are controlled by the sympathetic division and have become of recent interest as a physiological measurement.

Bumke [1911] was one of the earlier works that noted nonvisual processes influence pupillary changes. He noted that the pupil becomes dilated during epileptic siezures. Bumke stated:

> "In general every active intellectual process, every psychical effort, every nervous impulse (whether or not followed by a muscle action), every exertion of attention, every active mental image, regardless of content, particularly every affect just as truly produces pupil enlargement as does every sensory stimulus."

Kahneman [1969] posed the question as to whether the pupil was uniquely sensitive to mental effort, or whether comparable results could be obtained with other autonomic functions when these were synchronized to paced mental activity. He conducted an experiment in which the subjects performed a paced mental task at three levels of difficulty, while synchronized recordings of pupil diameter, heart rate,

and skin resistance were made. He reported that all three functions indicated an increase in sympathetic activity during information intake and processing and a corresponding decrease during report. However, the pupillary response gave the most consistent results.

Hess and Polt [1964] conducted an experiment in which simple multiplication problems were used as the material for mental activity. The results showed that changes in pupil diameter during the solving of simple multiplication problems can be used as a direct measure of mental activity. There was complete correlation between difficulty of the problem and the mean response of the five subjects tested. Simpson and Hale [1969] also reported that decision making was associated with an increase in pupil size.

Hope [1971] conducted an experiment using the same multiplication problems as were used by Hess and Polt. The analysis was expanded to include correct and incorrect problem solutions. For correct problem solutions the results confirmed those reported by Hess and Polt. However, for incorrectly computed problems, a decrease in pupil diameter was reported and the diameter continued to decrease as the degree of difficulty of the problems increased.

In view of the experiments discussed, an experiment was devised to test the hypothesis that the pupil diameter would increase with an increasing information processing rate, reach a maximum diameter at maximum information processing capacity, and rapidly constrict as the maximum information processing capacity was exceeded.

II. EXPERIMENTAL PROCEDURE

Pupil diameter was recorded using a chart recorder version of a model 831D television pupillometer manufactured by the Whittaker Corporation.

The television pupillometer utilizes a closed-circuit television system to observe the eye and a signal processor to measure and display pupil diameter. A low-intensity, near-infrared source illuminates the eye without discomfort or distraction to the subject. The television monitor displays the eye image from the camera, as modified by a signal processor, and provides instantaneous feedback on the quality of the measurement.

Pupil diameter is recorded continuously by the chart recorder with a scale of zero to ten millimeters. Recordings are made on a standard heat-sensitive paper by a pen with adjustable heat control.

The number of bits of information processed is defined as the logarithm to the base two of the number of equally likely alternatives to choose from. Thus, a one-bit and two-bit information processing task requires two and four equally likely alternatives to choose from, respectively. For an information processing task, a random list of the digits two and three and a random list of the digits one, two, three, and four were presented visually on a digital readout by means of a paper tape reader for a one-bit and two-bit task, respectively. The subject's required response

was to depress a pushbutton switch corresponding to the digit presented on the digital readout.

Two modes of operation, automatic and self-pace, were utilized. In the self-pace mode, a response by the subject activated the next presentation of a stimulus. In the automatic mode, an oscillator activated the presentation of the stimulus at regular, preset time intervals, whether or not the subject responded.

The accumulated total elapsed time from time of presentation until a response was made, the number of stimuli presented, and the number of responses made were recorded for each run. The total number of bits of information processed was determined by multiplying the number of responses made times the number of bits of the task. In the self-pace mode of operation, the total number of bits processed divided by the accumulated total elapsed time was taken as a measure of maximum information processing capacity.

Each subject was briefed that a list containing the digits two and three at random would be presented on the digital readout located approximately 30 inches in front of him at eye level and that he was to respond as quickly as possible. The required response was to depress a pushbutton switch with his left index finger when the digit two appeared and to depress a pushbutton switch with the right index finger when the digit three appeared while his eyes remained fixated on the digital readout, which enabled the pupil diameter to be recorded continuously on the chart

recorder. Each subject was told that incorrect responses would be recorded automatically and would detract from his overall "score". Each subject was further briefed that during the initial part of the experiment the lighted digit on the display would remain on until he depressed the appropriate pushbutton switch on the response panel causing the next digit in the sequence to light immediately. He was told that the number of correct responses made would determine his maximum information processing capacity.

The subject was then requested to place his head in a standard, curved metal head holder, placing his chin on the accompanying, adjustable, chin rest. His left and right index fingers were then placed on the appropriate switches on the response panel. After he was properly positioned for viewing by the television camera, he was requested to fixate on the lighted display. The television camera was then finely adjusted by means of a joy-stick and focused on the left eye to provide an optimum position for recording the pupil diameter.

After the correct display was obtained on the television screen and a stable baseline pupil diameter was observed on the recording paper, the subject was given a 15 second test in the self-pace mode to determine his maximum information processing capacity.

The subject was then told to relax and fixate on the lighted display while the appropriate time settings were made for automatic presentation of stimuli at 50, 75, and

125 percent of his maximum processing rate. The subject was then briefed that the next part of the experiment consisted of a 45 second time interval during which the lighted digit on the digital readout would change at a preset time whether or not he depressed the appropriate response switch and that he was to attempt to make the correct response within the preset switching time. He was further briefed that during the initial part of the test he would have no difficulty in making the correct response within the required time but that as the test progressed it would become increasingly difficult to make the required response within the given time.

The second part of the experiment was then started which consisted of: (1) 15 second run at 50% of maximum capacity, (2) 15 second run at 75% of maximum capacity, and (3) 15 second run at 125% of maximum capacity. At each 15 second interval the rate of presentation was changed by switching to the predetermined time set on the oscillator and simultaneously depressing an event mark on the graph recorder.

The subject was allowed to move away from the head rest while the tape on the tape reader was changed for a two-bit task. The experiment was then repeated exactly as before except that the subject was required to depress switches one and two with the middle and index fingers, respectively, of his left hand whenever digits one and two appeared on the digital readout and to depress switches three and four with the index and middle fingers, respectively, of his right hand whenever the digits three and four appeared.

III. DISCUSSION AND RESULTS

The percentage changes in pupil diameter for the one-bit information processing task are recorded in Table I.

TABLE I

PERCENTAGE CHANGE IN PUPIL DIAMETER DURING A ONE-BIT INFORMATION PROCESSING TASK

The diameter was measured prior to beginning the information processing task and compared to the maximum diameter for each presentation rate.

SUBJECT	RATE OF PRESENTATION			
	1/2 x self-pace rate	3/4 x self-pace rate	self-pace	5/4 x self-pace rate
1	9.4	12.1	21.9	-4.4
2	-9.5	-4.7	-4.7	7.5
3	9.3	4.8	-5.5	-9.3
4	8.0	4.5	14.9	-5.3
5	7.3	4.9	16.1	-10.1
6	2.3	7.3	-8.7	-4.9
7	5.4	-2.3	8.8	-5.6
8	7.5	23.1	17.2	-6.7
9	2.2	8.6	20.8	-13.7
10	8.0	12.0	6.0	3.0
Means	4.99	7.03	8.68	-4.95

The percentage changes in pupil diameter for the two-bit information processing task are recorded in Table II.

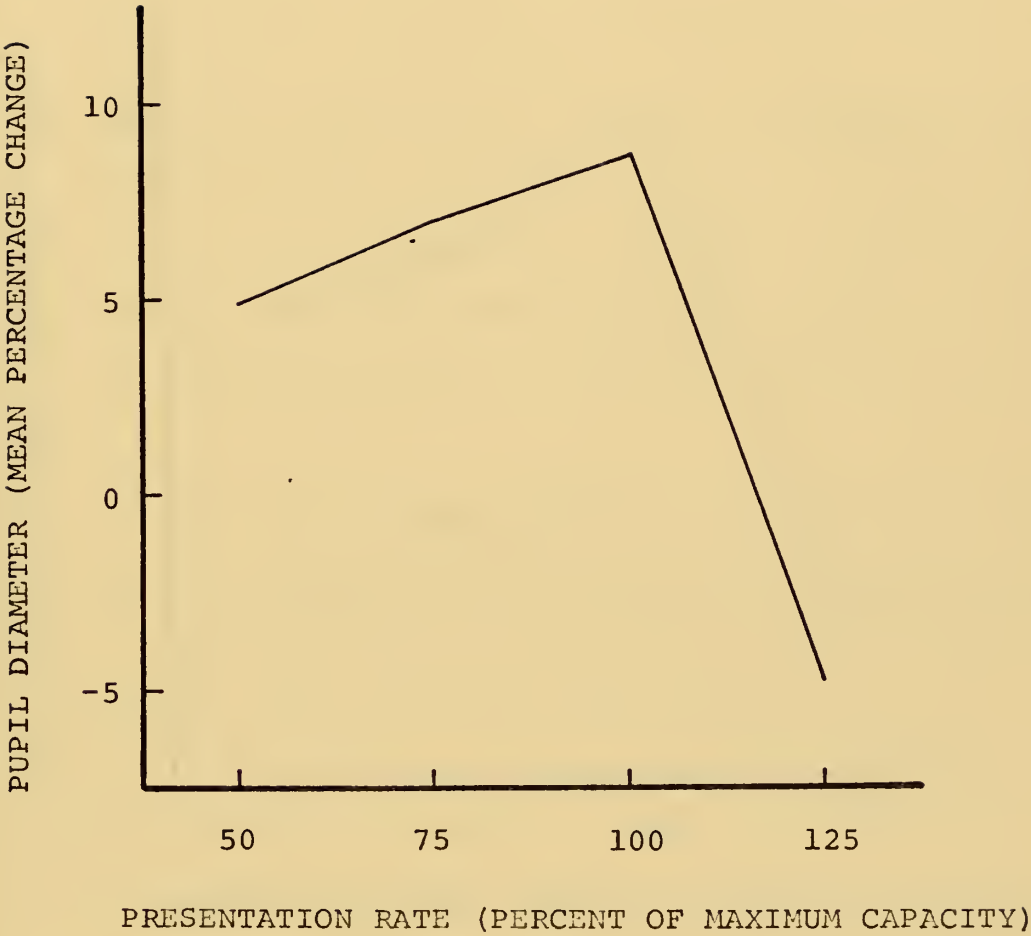
TABLE II

PERCENTAGE CHANGE IN PUPIL DIAMETER DURING A TWO-BIT INFORMATION PROCESSING TASK

The diameter was measured prior to beginning the information processing task and compared to the maximum diameter for each presentation rate.

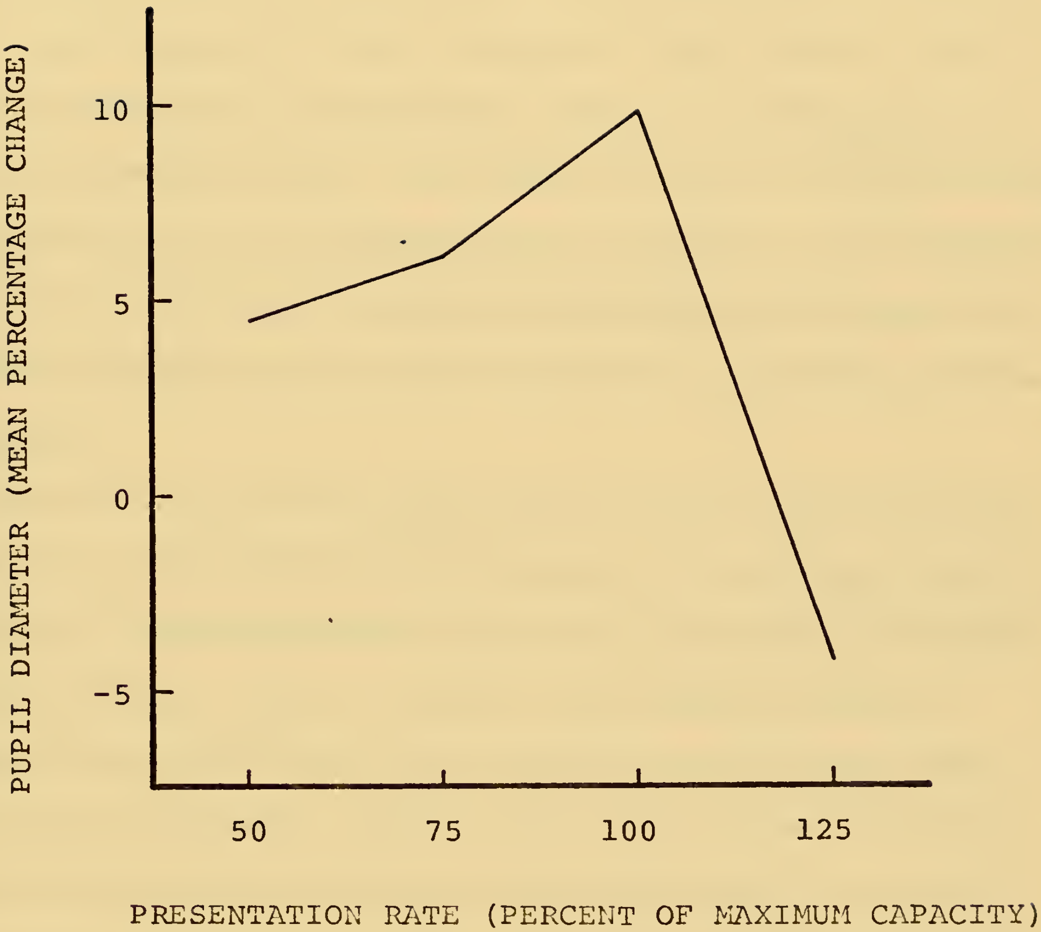
SUBJECT	RATE OF PRESENTATION			
	1/2 x self-pace rate	3/4 x self-pace rate	self-pace	5/4 x self-pace rate
1	4.0	11.4	8.9	-11.1
2	4.5	4.5	9.3	-5.0
3	6.5	-2.2	4.4	6.9
4	11.1	15.6	12.2	8.9
5	8.5	17.0	21.3	-2.2
6	6.7	9.3	-11.1	-8.9
7	11.1	4.5	8.9	-13.3
8	-20.5	-19.2	14.1	-18.0
9	9.3	11.6	25.5	4.6
10	4.0	8.0	6.0	-5.6
Means	4.52	6.05	9.95	-4.37

Inspection of Figures 1 and 2 reveals that the mean percentage changes in pupil diameter for the one-bit and two-bit tasks supported the hypothesis. Mean pupil diameter increased with an increasing information processing rate and constricted for an information processing rate qreater than maximum capacity. Inspection of Table I and Table II shows average percentage decreases in pupic diameter of 13.6 and 14.3 when going from maximum processing capacity to a 25 percent overload for the one-bit and two-bit task, respectively.



MEAN PERCENTAGE CHANGE IN PUPIL DIAMETER VS. PRESENTATION RATE FOR A ONE-BIT INFORMATION PROCESSING TASK.

FIGURE 1



MEAN PERCENTAGE CHANGE IN PUPIL DIAMETER VS. PRESENTATION RATE FOR A TWO-BIT INFORMATION PROCESSING TASK.

FIGURE 2

It is interesting to note subject two's percentages for the one-bit task since his pupil diameter changed in a direction opposite to that hypothesized. His maximum constriction occurred while being required to process at a rate of one-half of his maximum capacity and overload resulted in pupillary dilation as opposed to the hypothesized constriction. For the one-bit task, subjects three and six also experienced pupillary constriction during the self-pace or maximum processing rate. No attempt is made to explain these unexpected pupillary changes except to present the hypothesis that during information processing pupillary changes occur and these changes may be either positive or negative for an individual.

Inspection of Table II for the two-bit task shows that subject two experienced pupil changes in directions opposite to those he experienced for the one-bit task for the different presentation rates. Subject three showed opposite changes during the normal and overload presentation rates. For the two-bit task, subject eight's direction of changes do not correspond to those he experienced for the one-bit task during the one-half times self-pace and three-fourths times self-pace rates.

Some parasympathetic pupillary reflex was present due to the changing digits on the digital readout. However, this change was very small when compared to the changes due to mental activity and motor response. This effect appears to be unavoidable when using visual stimuli to study pupillary

size changes. One possible means of reducing the parasympathetic pupillary reflex is to encircle the digital readout with several light sources of constant intensity, thereby reducing the change in overall light intensity when the digits are changed on the lighted display.

Auditory stimulation was also present due to the tape reader and relays. It was orginally intended to use a white noise generator to mask out unwanted auditory stimuli. However, this proved to be ineffective due to the loud noise level produced by the tape reader, relays, and associated equipment. One solution to this problem is to remove the tape reader and associated equipment from the vicinity of the subject.

Since pupillary changes during an information processing task appear to be more complex than was orginally hypothesized, the following experimental design is offered for any future experiments of this nature. A randomized block factorial design [Kirk 1968] would permit testing for any significant difference in pupillary changes between subjects. In this design the rates of presentation would have to be presented in a random order for each subject rather than from least difficult to most difficult as was done here. A randomized block factorial design would also permit calculating the required sample size for the desired level of significance.

This experiment showed that the trend in pupillary size changes during an information processing task is for the

pupil diameter to increase with an increasing information processing rate, reach a maximum at maximum information processing capacity, and rapidly constrict as maximum information processing capacity is exceeded.

BIBLIOGRAPHY

Bumke, O., Die Pupillenatörungen, Bei Geistesund Nervenkronkheiten, Fisher, 1911.

Hess, Eckhard H. and Polt, James M., "Pupil Size in Relation to Mental Activity During Simple Problem-Solving," Science, V. 143, p. 1190-1192, 1964.

Hope, Robert E., Pupillary Size Change As Correlated With Mental Activity, M.S. Thesis, Naval Postgraduate School, 1971.

Kahneman, Daniel, "Pupillary, Heart Rate, and Skin Resistance Changes During a Mental Task," Journal of Experimental Psychology, V. 79, p. 164-167.

Kirk, Roger E., Experimental Design: Procedures For the Behavioral Sciences, Brooks/Cole Publishing Co., p. 237, 1968.

Simpson, H. M. and Hale, Shirley M., "Pupillary Changes During a Decision-Making Task," Perceptual and Motor Skills, V. 29, p. 495-598, 1969.

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